Early experience with the snorkel technique for juxtarenal aneurysms

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Objective: **The lack of readily available branched and fenestrated endovascular aneurysm repair (EVAR) options has created an opportunity for creative deployment of endograft components to treat juxtarenal aneurysms. We present our early experience with "snorkel" or "chimney" techniques in the endovascular management of complex aortic aneurysms.**
Methods: **We retrospectively reviewed planned snorkel procedures for juxtarenal aneurysms performed from September 2009 to August 2011. Our standardized technique included axillary or brachial cutdown for delivery of covered snorkel stents and mostly percutaneous femoral access for the main body endograft.**
Results: **Fifty-six snorkel grafts were successfully placed in 28 consecutive patients (mean age, 75 years) with juxtarenal aneurysms. Mean aneurysm size was 64.8 mm (range, 53-87 mm). The snorkel configuration extended the proximal seal zone from an unsuitable infrarenal neck for standard EVAR (median diameter, 33.5 mm; length, 0.0 mm) to a median neck diameter of 24.5 mm and length of 18.0 mm. Five patients had unilateral renal snorkels, 17 had bilateral renal snorkels, and six had celiac/superior mesenteric artery/renal combinations. Technical success of snorkel placements was 98.2%, with loss of wire access leading to one renal stent deployment failure. Thirty-day mortality was 7.1%: one patient was readmitted 1 week postoperatively with pneumonia and died of sepsis; one patient died at 1 week of a right hemispheric stroke. Other major complications included perinephric hematomas, 7.1%; permanent hemodialysis, 3.6%; iliac artery injury requiring endoconduit placement, 3.6%; and brachial plexus nerve injury, 3.6%. Cardiac complications included self-limited arrhythmias (14.3%) and one non-Q-wave myocardial infarction (3.6%), with all recovering without coronary intervention. Mean follow-up was 10.7 months (range, 3-25 months). One patient died of nonaneurysmal-related causes at 3 months (89.3% survival). Postoperative imaging revealed one renal snorkel graft occlusion occurring at 3 months (98.2% overall primary patency). Seven (25%) early endoleaks were noted on the first follow-up computed tomography angiography: two type I, three type II, and two type III (25%), leading to one secondary intervention (3.6%) with bridging cuff placement (type III). The small type Ia endoleaks and other type III endoleak resolved at the 6-month scan. Mean sac regression at the latest follow-up was 7.3 mm. No aneurysm has enlarged on postoperative imaging.**
Conclusions: **Early success with the snorkel technique for juxtarenal aneurysms has made it our procedure of choice for complex short-neck to no-neck EVAR. Although long-term follow-up is needed, the flexibility of the snorkel technique and lack of requirement for custom-built devices may make this approach more attractive than branched or fenestrated stent grafts. (J Vasc Surg 2012;55:935-46.)**

Endovascular aneurysm repair (EVAR) has gained widespread acceptance as the procedure of choice for patients with infrarenal abdominal aortic aneurysms (AAAs) and suitable aortic anatomy. Since the procedure was first conceived,[1] ongoing technical improvements, maturation of stent graft technology, surgeon experience, and patient preference have extended indications for repair to patients with more challenging anatomy. As a result, EVAR has constituted an ever-increasing proportion of elective and emergency AAA procedures.[2,3] Despite these advances, the most common anatomic limitation to EVAR remains the proximal neck, one of the key predictors of long-term outcome and success.[4-6]

From the Division of Vascular Surgery, Stanford University Medical Center.
Competition of interest: none.
Presented at the Twenty-sixth Annual Meeting of the Western Vascular Society, Kaua'i, Hawaii, September 18-20, 2011.
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The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a competition of interest.
0741-5214/$36.00

doi:10.1016/j.jvs.2011.11.041

The optimal approach to the suprarenal or juxtarenal aortic aneurysm (JAA), often with severely compromised proximal necks, remains controversial. Although open repair is an effective and durable option for patients with JAA, particularly in centers of excellence for patients at low physiologic risk,[7,8] fenestrated and branched EVAR (FBE) in other parts of the world have emerged as effective, potentially less invasive alternatives.[9-11] In the United States, however, lack of widespread availability of FBE has allowed other techniques to emerge, namely open debranching,[12-14] homemade fenestrations,[15] and the "snorkel" or "chimney" configuration.

First described by Greenberg et al,[16] the snorkel strategy consists of placing of parallel stents or stent grafts adjacent to the endograft main body to maintain perfusion to renal and visceral branches after aneurysm exclusion. This approach can be used as a bailout from accidental coverage of vital side branches during deployments requiring close approximation of the main body to the branch artery in question or for the intentional cranial relocation of the EVAR seal zone for JAAs.[17-22] After developing some experience with a variety of these techniques for aneurysms with complex anatomy, we examined our early results with planned snorkel EVAR

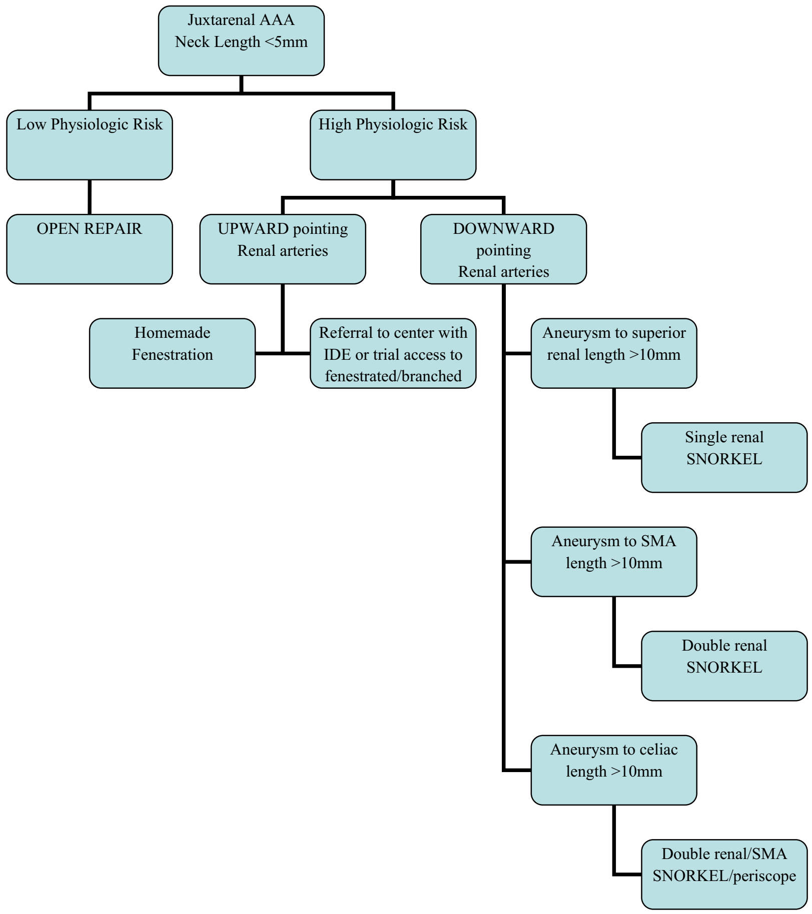

Fig 1. Current algorithm for surgical and endovascular management of juxtarenal abdominal aortic aneurysms (*JAAAs*). *IDE,* Investigational device exemption; *SMA,* superior mesenteric artery.

(Sn-EVAR) to determine whether continued use of this technique was justified by our early-term and intermediate-term outcomes.

METHODS

The study methodology and design was approved by the Stanford Institutional Review Board.

Patient selection. All patients treated electively with Sn-EVAR from September 2009 to August 2011 at Stanford University Medical Center were retrospectively identified from a prospectively maintained database. Additional patient information, including demographics, comorbidities, and outcome variables, were obtained through review of inpatient and outpatient clinical records. Only patients with planned intentional coverage of renal or visceral branches with the main body endograft, or both, and parallel adjacent placement of snorkel graft(s) were included in this analysis. Patients in this series underwent first-time repair of JAAs, repair of JAAs and para-JAAs after prior open infrarenal AAA repair, or revision of previous EVAR with persistent type I endoleaks. No patients with ruptured or leaking AAAs were treated with this configuration. No devices were modified or altered before implantation.

Our treatment algorithm was similar to that described by Bruen et al[21] and Coscas et al[22] with notable differences (Fig 1). Although we have had experience with homemade fenestrated or branched grafts,[23] we do not have routine access to FBE, as described by Coscas et al,[22] as an alternative to Sn-EVAR and did not include those cases in this analysis. Because no specific guidelines exist to define the amount of graft apposition required to achieve the optimal seal within the snorkel configuration, we somewhat arbitrarily planned for at least 10 mm of "suitable" neck and placed snorkels in single renal, bilateral renal, or occasionally, included superior mesenteric artery (SMA)/celiac branches as necessary to maintain an appropriate seal (Fig 1).

When more than two snorkel stents were required (four patients in this series), we used a "terrace" configuration or "sandwich" strategy with stacked endograft cuffs and a maximum of two snorkels in a particular plane[24,25] or the "periscope" configuration with downward pointing parallel endografts to provide additional branch preservation.[26]

These modifications to provide additional branch preservation were based on the premise that more than two snorkel stents theoretically displaces the main body endograft too much or creates too large of a gutter, or both.[24-26] Of note, because most renal and visceral arteries point downward, the periscope configuration was only attempted in three renal arteries, successfully deployed in two, and should be considered an adjunct to the snorkel strategy.[23]

Anatomic evaluation. All available preoperative, intraoperative, and postoperative imaging was assessed on a three-dimensional workstation using AquariusNET software (TeraRecon Inc, San Mateo, Calif). All reported preoperative AAA morphologic parameters are measured on the centerline, unless otherwise noted, and include maximum aortic, neck length, neck diameter, neck angulation, neck shape, neck thrombus, maximum common iliac diameter, associated iliac aneurysm, and iliac tortuosity. Particular to Sn-EVAR, additional measurements defined in this series were the "improved" or "snorkel" neck to document the intended landing zone of the proximal placement of the main body endograft. Contraindications to the Sn-EVAR approach included extreme tortuosity, calcification, or atheroma of the planned neck, most often between the SMA and renal arteries. By our treatment algorithm, patients with prohibitive anatomy, even for the snorkel strategy, were then counseled about open surgery or no intervention at all.

In addition to abdominal and pelvic images and reconstructions, thoracic computed tomography (CT) scans were also obtained to delineate arch and left subclavian anatomy for snorkel sheath placement. Postoperative radiographic follow-up consisted of a postprocedural CT angiography (CTA) $\leq$1 month, at 6 months, and yearly thereafter. Patients with renal insufficiency undergo duplex imaging of the snorkeled branch vessels, AAA sac to assess endoleak, and noncontrast CT to evaluate kinking or compression of the snorkel stents.

Procedural technique. The overall sequence of steps has been described by others.[17-22] Ours is similar, with important differences. All procedures were performed in our hybrid endovascular suite with fixed floor-mounted imaging (Siemens Medical Solutions USA, Malvern, Pa) by two attending vascular surgeons (J.T.L. and R.L.D.) working from the right femoral and left axillary positions.

General anesthesia is initiated, continuous arterial monitoring from the right radial artery, and peripheral vs central venous access is obtained, depending on the patient. The left arm is outstretched and prepared circumferentially. Antegrade visceral/renal access is obtained from open exposure of the subclavian, axillary, or proximal brachial arteries, separately or in combination, depending on their diameter and the number of planned snorkel grafts. While access is being obtained from the axillary position, percutaneous femoral access is obtained using the "Preclose" technique, whenever possible.[27]

Up to three 7F 90-cm Pinnacle Destination sheaths (Terumo Medical, Somerset, NJ) can be inserted into the left axillosubclavian arterial system when positioned properly, without the need for conduit placement. Right axillary sheath access was also obtained in one patient to perform a "triple" snorkel strategy.

Systemic heparinization is initiated on placement of the sheaths, with an activated clotting time of >300 seconds maintained throughout the duration of the procedure.

Through the antegrade sheaths, the targeted renal and visceral branches are cannulated using 260-cm-long hydrophilic guidewires and a 125-cm JB1 catheter (Cook Medical, Bloomington, Ind). Once cannulated, the sheaths are advanced coaxially into the target artery orifice. When necessary, the soft hydrophilic guidewire is exchanged for a 260-cm J-tip Rosen wire (Cook Medical) or Amplatz Superstiff (Boston Scientific, Natick, Mass) to facilitate sheath advancement. Balloon-expandable (5-, 6-, or 7-mm $\times$ 59-mm-long) covered iCAST stents (Atrium Medical, Hudson, NJ) or Viabahn (W. L. Gore and Assoc, Flagstaff, Ariz) low-profile self-expanding covered stents are advanced through the sheaths into the target branch vessel, depending on the tortuosity of the orifice and its axis with the aorta (Fig 2, *A*). If self-expanding covered stents are used, additional bare-metal balloon expandable stents are placed within the Viabahn for additional radial force.

From the femoral access sites, the main body endograft is advanced and positioned in the usual fashion. In this series, the Zenith bifurcated system (Cook Medical) was used in 19 patients (68%). Other endograft systems included two Renu devices (Cook Medical), two TX2 (Cook Medical), two Endurant (Medtronic AVE, Santa Rosa, Calif), one Excluder (W. L. Gore), one TAG (W. L. Gore), and one Talent (Medtronic AVE). Main body endograft device choice was made based on availability and sizing of the endografts, which was based on the intended landing zone and often "oversized" to ~20% to 25% to account for the additional fabric infolding to accommodate the snorkel stent(s). The Cook Zenith was favored due to active proximal fixation, as well as longer path lengths of treatment necessary from the proximal landing zone of the SMA to the internal iliac arteries and the modular design with two docking limbs to facilitate minimal cuff usage. Multiple snorkels did not increase the oversizing over single snorkels. The main body endograft is positioned at the planned deployment site, most often immediately below the SMA, best visualized via a near-lateral C-arm position (Fig 2, *B*). The main body endograft is then unsheathed to the contralateral gate, and gate cannulation attained in the usual manner.

Once successfully cannulated, a compliant molding proximal balloon is advanced to the top of the fabric of the main body. Simultaneously, the antegrade sheath(s) are withdrawn from the renal/visceral orifices and snorkel stents positioned for final deployment, typically 2 to 3 cm into the target branch vessel. Care was taken to select snorkel stents with sufficient length (usually the 59 mm iCAST or the 50 mm Viabahn) to ensure that the proximal edge of the snorkel stent remained clear of the proximal

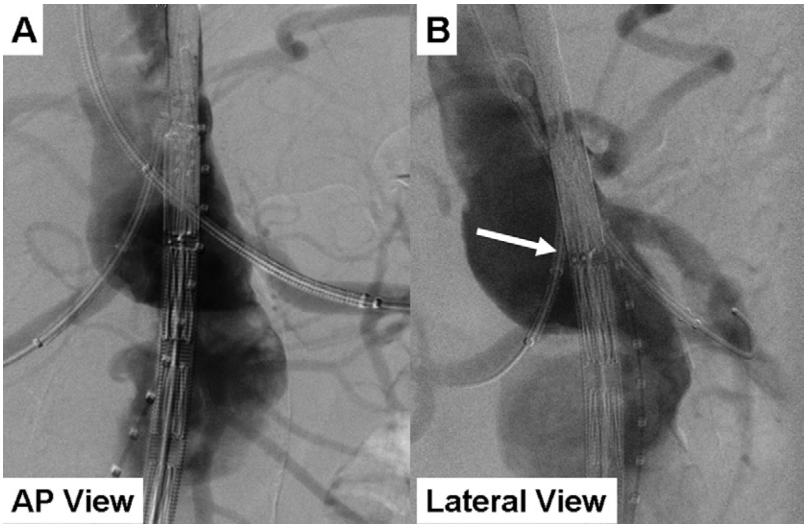

Fig 2. A, Anteroposterior (*AP*) and **(B)** lateral views of snorkel setup with bilateral iCAST stents positioned in the renal artery origins. This juxtarenal aneurysm had significant infrarenal thrombus precluding an adequate proximal seal with a standard device. The *arrow* that signifies the most proximal portion of the fabric of the endograft immediately deployed to the level of the superior mesenteric artery to maximize endograft neck apposition.

endograft fabric edge. After this, a deliberate sequence of deployment and balloon molding is initiated (Fig 3) in a "triple kissing" fashion to assure an optimal theoretic seal and minimization of "gutter" channels around each snorkel stent. After completion of the proximal portion of the procedure, angiography verifies no proximal type I endoleak, and the iliac limbs are then deployed in the standard fashion while maintaining wire access to the snorkel grafts.

At the conclusion of the procedure, patients were usually extubated, monitored in the intensive care unit overnight, and then sent to the surgical ward. Clopidogrel and aspirin were given, if the patients were not already taking those medications, for at least 6 weeks postoperatively.

RESULTS

Sn-EVAR was offered to 28 (71% men) consecutive patients who were determined to be at excessive risk for open operative repair with suprarenal clamping. Demographics and AAA morphology of the study cohort are listed in Table I. Mean age for the cohort was 75 years (range, 60-86 years), with mean aneurysm size of 64.8 mm (range, 53-87 mm). Comorbidities of this high physiologic risk cohort were typical for AAA patients and included hypertension (100%), hyperlipidemia (93%), coronary artery disease (79%), severe chronic obstructive pulmonary disease, (46%), and stage III or worse congestive heart failure (32%). All patients were American Society of Anesthesiologists class 3 or worse and felt to be unsuitable candidates for major open operation by their primary cardiologist and the operative team.

Most patients had asymptomatic newly discovered JAAs (79%), with four patients (14%) having previous EVAR with type I endoleaks, and two patients (7%) with previous open repair and formation of para-anastomotic JAA. Infrarenal neck measurements were prohibitive for routine EVAR, with median neck diameter of 33.5 mm (range, 18-45 mm) and median neck length of 0.0 mm (range, 0-5 mm). After applying the algorithm shown in Fig 1, the planned placement of the proximal endograft allowed conversion to a "snorkel" neck that was much more suitable, with a median neck diameter of 24.5 mm (range, 18-32 mm) and a median neck length of 18.0 mm (range, 10-30 mm).

Perioperative outcomes are listed by patient in Table II and for the entire group in Table III, along with postoperative issues and follow-up. Bilateral renal snorkels were placed in 17 patients (61%), unilateral renal snorkels in five (18%), and celiac/SMA/renal combinations in six (21%). We attempted to preserve 57 branches in the 28 patients and were able to deploy 56 snorkel grafts (98.2% technical success). No functional renal artery was intentionally covered at the outset (in distinction to Bruen et al[21]). One renal artery was lost during deployment of a Viabahn periscope graft during an attempted four-branch Sn-EVAR due to inadequate wire fixation into the target branch and loss of access as the Viabahn pulled out during deployment. This renal artery was then subsequently covered when we were unable to regain access and led to a threefold rise in the patient's postoperative creatinine levels. This patient never required hemodialysis and recovered baseline renal function with a stable creatinine. No endoleak was noted on his 6-month follow-up CTA, and the remaining three snorkel stents were all patent, without kinking or compression.

Overall 30-day mortality was 7.1%, occurring in one patient readmitted 1 week postoperatively with pneumonia who ultimately died of sepsis, although his postoperative CTA showed successful exclusion of his juxtarenal aneu-

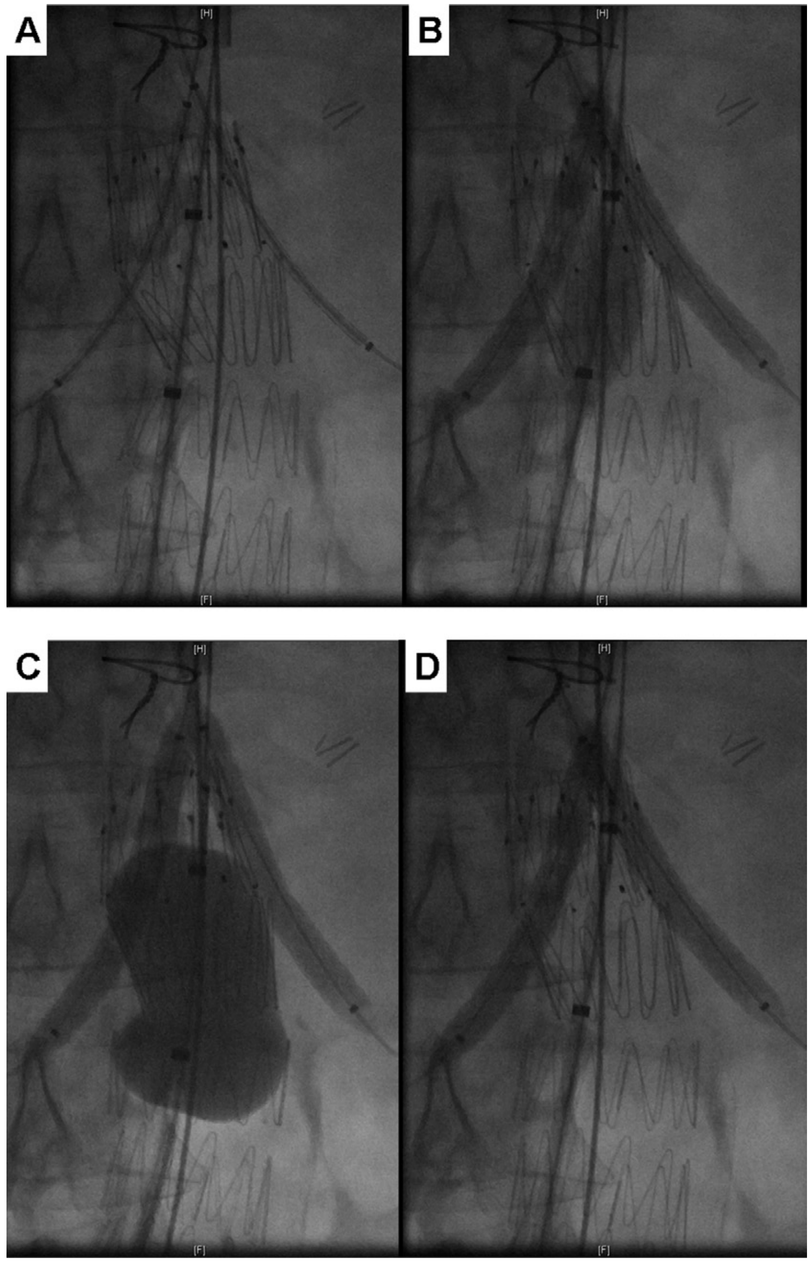

Fig 3. **A,** Deliberate "triple-kissing" balloon angioplasty for double-renal snorkel case, with renal balloons inflated **(B)** while molding endograft balloon is inflated **(C)** and then deflated **(D)**.

rysm with patent bilateral renal snorkels. A second early death occurred in a patient with attempted triple snorkel with right axillary access for one of the renal stent deployments. The case was additionally complicated by an iliac rupture requiring endoconduit and 2 L of blood loss, but final angiography showed no endoleak and good perfusion of both renal arteries/SMA. The patient awoke with a moderate right hemispheric stroke that progressed over 5 days postoperatively to a hemorrhagic infarct. The family refused neurosurgical intervention and she died. Her postoperative abdominal CTA showed patent bilateral renal and SMA snorkel stents, with exclusion of her 6-cm JAA.

Other major complications included two perinephric hematomas from wire manipulation (7.1%) requiring blood transfusion, two patients with renal dysfunction (one mentioned above), with one needing permanent hemodialysis (3.6%), and one patient with brachial plexus injury leading to transient left arm weakness (3.6%). The patient currently requiring hemodialysis was a double-snorkel/single periscope combination to preserve both renal arteries and SMA

Table I. Abdominal aortic aneurysm (*AAA*) morphology

				AAA size	*Infrarenal neck, mm*		*Intended snorkel neck, mm*	
Pt	*Age*	*Sex*	*Indication*	*(mm)*	*Length*	*Diameter*	*Length*	*Diameter*
1	84	M	Type I endoleak	62	2	31	10	27
2	80	F	Elective	84	3	23	18	23
3	72	M	Elective	61	0	34	15	25
4	86	M	Elective	75	0	29	22	25
5	76	M	Elective	62	0	34	15	29
6	64	F	Elective	55	0	38	18	18
7	77	M	Elective	60	0	34	30	25
8	75	M	Type I endoleak	76	5	29	25	24
9	75	M	Type I endoleak	70	0	32	20	25
10	71	M	Elective	59	5	33	20	32
11	68	M	Elective	69	0	18	12	21
12	76	F	Elective	67	0	35	10	22
13	81	F	Elective	53	1	22	10	21
14	70	M	Type I endoleak	74	0	30	20	24
15	82	M	Para-anastomotic	60	0	36	17	21
16	73	F	Elective	72	4	30	15	23
17	68	M	Elective	68	0	36	30	27
18	80	M	Elective	87	4	28	17	24
19	84	M	Elective	54	0	36	20	32
20	72	F	Elective	54	2	28	18	21
21	66	M	Elective	58	4	36	15	31
22	85	M	Para-anastomotic	60	0	38	25	29
23	78	F	Elective	60	0	33	18	26
24	80	F	Elective	60	0	36	13	21
25	71	M	Elective	75	3	40	22	24
26	60	M	Elective	61	2	42	19	27
27	76	M	Elective	55	4	22	14	21
28	76	M	Elective	62	0	45	20	30

F, Female; *M,* male.

who developed contrast-induced acute tubular necrosis with patent renal snorkels.

The two perinephric hematoma complications occurred early in the Sn-EVAR experience and were likely due to inadvertent advancement of a stiff hydrophilic wire tip during snorkel stent delivery. We have since switched to the J-tip Rosen wire during sheath and stent advancement to reduce the risk of renal perforation and bleeding. The brachial plexus injury also occurred early in the experience and led to preferential access of the distal axillary artery high in the axilla rather than an infraclavicular approach as the primary access site for antegrade sheath placement.

Cardiac complications included four self-limited arrhythmias (14.3%) and one non–Q-wave myocardial infarction (3.6%), all resolved in follow-up without coronary intervention. During a mean follow-up of 10.7 months (range, 3-25 months), one additional patient died of a nonaneurysmal related cause at 3 months. No patient has been lost to follow-up at this time.

Follow-up imaging revealed one renal snorkel graft occlusion (98.2% overall primary patency) at 3 months in an asymptomatic patient without change in renal function. Seven (25%) early endoleaks were also noted on first follow-up CTA (two type I, three type II, one type III) leading to one secondary intervention (3.6%) consisting of extender cuff placement (type III). Both patients with small type Ia endoleaks resolved at the 6-month CTA. Mean sac regression for the entire cohort at latest follow-up was 7.3 mm, and no aneurysm has enlarged in follow-up nor ruptured.

DISCUSSION

Our initial experience with the Sn-EVAR technique is favorable: 28 patients were treated, with an acceptable 7.1% 30-day mortality given the relatively high case mix index, and one additional, nonaneurysm related death occurred in short-term follow-up, for 89.3% survival. Estimates of the 1-year mortality for patients undergoing open repair of similar JAAs, given the attendant cardiopulmonary comorbidities, range as high as 30%.[8] In this regard, our experience reinforces and extends the results of previous investigators[17-22] that Sn-EVAR offers acceptable surgical outcomes, with reduced operative risk, for high-risk physiologic patients. Our results also provide further impetus for continued innovations to provide a total endovascular strategy for JAAs.

Technical success and early outcomes reported by prior investigators[17-22] reveal a surprising lack of type Ia endoleaks requiring reintervention, which is echoed in this series of Sn-EVAR. The two small type I endoleaks identified in follow-up subsequently resolved spontaneously. This gutter-sealing phenomenon, likely due to the juxtaposition of the

Table II. Operative strategy, snorkel components, and complications

Pt	*Main body*	*Snorkel configuration*	*Stent type*[a]	*Endoleak*	*F/U time (months)*	*Complications, F/U*
1	32 Renu	Left renal	iCAST	I	25	Endoleak resolved at 6 months
2	28 Zenith	Bilateral renal	iCAST	None	25	
3	32 Talent	Left renal	iCAST	None	20	
4	32 Zenith	Bilateral renal	iCAST	II	19	Brachial plexus injury
5	36 Zenith	Left renal	iCAST	None	18	
6	22 Zenith	Bilateral renal	iCAST	None	18	
7	32 Zenith	Bilateral renal	iCAST	III	18	
8	32 Zenith	Bilateral renal	iCAST	II	17	Renal branch injury
9	32 Zenith	Bilateral renal	iCAST	III	16	Renal branch injury, had 2nd intervention
10	36 Zenith	Left renal	iCAST	None	12	
11	26 Zenith	Bilateral renal	iCAST	None	10	Occluded left renal snorkel
12	28 Endurant	Bilateral renal	iCAST	None	3	Died of MI, 3 months post-op
13	28 Zenith	Right renal	Viabahn	None	9	
14	32 Zenith	Bilateral renal	Viabahn	1	8	Endoleak resolved at 6 months
15	28 Zenith	Bilateral renal	iCAST	None	8	
16	28 Zenith	Bilateral renal	Viabahn	None	7	
17	34 TAG	Left renal/SMA/celiac	Viabahn	None	7	Lost right renal access, post-op renal insufficiency resolved by 6 months
18	31 Excluder	Bilateral renal	Mixed	None		Died of pneumonia, post-op day 8
19	38 TX2	SMA/celiac	Viabahn	None	4	
20	28 Zenith	Right renal/SMA	iCAST	None	4	
21	36 Zenith	Bilateral renal	iCAST	None	4	
22	36 Renu	Bilateral renal/SMA	Mixed	None	3	Renal failure at 3 mon, on dialysis
23	32 Zenith	Bilateral renal/SMA	Mixed	None		Died of stroke post-op day 7
24	26 Zenith	Bilateral renal	Mixed	None	3	
25	30 Zenith	Bilateral renal	iCAST	None	3	
26	36 Zenith	Bilateral renal	iCAST	None	3	
27	28 Endurant	Bilateral renal	ICAST	None	3	
28	36 TX2	Bilateral renal/SMA/celiac	Mixed	3	3	Endoleak resolved at 3 months

SMA, Superior mesenteric artery.
[a]Balloon-expandable or self-expandable.

Table III. Perioperative outcomes and imaging follow-up

Variable	*Median*	*Range*
Perioperative		
Fluoroscopy time, minutes	63.5	37 to 155
Contrast dose, mL	154.0	66 to 400
Operative time, min	202.5	135 to 515
Estimated blood loss, mL	400	100 to 2000
Creatinine, mg/dL		
Baseline	1.1	0.8 to 1.6
Highest post-op	1.4	0.9 to 5.8
Long-term follow-up	1.2	0.8 to 4.4
Length of stay, days		
Intensive care unit	1.0	0 to 6
Total hospital	4.0	2 to 10
Follow-up		
Pre-op aneurysm size, mm	61.5	54 to 87
Post-op sac size, mm	56.0	32 to 84
Sac regression at latest follow-up, mm	6.0	−1 to 23
Follow-up time, months	10.7	3 to 25

snorkel gutters and main body endograft fabric, has occurred independent of specific snorkel/endograft combinations and is likely related to the length and resistance offered by the gutters.[17-22] Longer-term follow-up will be necessary to verify, however, that the proximal fixation remains stable and without unique complications as more experience is accumulated. When reviewing the results of all currently published series as of October 2011 describing variations on the snorkel or chimney technique for JAAs (Table IV), endoleak rates are comparable to nonadjunct EVAR and compare well with fenestrated and branch EVAR. Overall branch vessel patency is at least 94%, comparable to that reported for FBE.[9-11] These acceptable results have piqued the interest of many surgeons to adopt similar approaches to the management of JAA in the absence of approved or widely available devices for FBE.

Several components outlined in our algorithm and techniques contribute to the favorable results observed in our current series. Careful patient selection by anatomy to assure that the snorkel strategy will provide an adequate seal is necessary. Contraindications to this approach would be similar to standard EVAR in a standard neck; ie, if there is extensive calcification, tortuosity, or atheroma in the planned snorkel neck, the operative plan is not likely to succeed. Extensive preoperative measurement and assessment, facilitated by three-dimensional workstation-managed image review and reconstruction, has allowed us to preselect anatomy that is favorable, albeit through a learning curve.

Table IV. Reported literature of snorkel/chimney endovascular aortic aneurysm repair for juxtarenal abdominal aortic aneurysms (*AAAs*)

Chimney/snorkel series for AAAs (first author)	*No.*	*Urgent (%)*	*Snorkels per patient (mean)*	*Covered stents (%)*	*Type I endoleak (%)*	*6-month patency (%)*	*30-day mortality (%)*
Ohrlander[17]	6	84	1.8	100	0	100	0
Hiramoto[18]	8	NA	1.0	12.5	12.5	100	0
Allaqaband[19]	2	0	1.0	50	0	100	0
Donas[20]	15	33	1.0	100	6.7	94	0
Bruen[21]	21	5	1.7	100	4.8	94	4.8
Coscas[22]	16	25	1.6	100	12.5	96	12.5
Current series	28	0	2.0	100	7.1	98	7.1

NA, Not available.

Extensive procedural planning, as outlined in the procedural steps, has also helped to steadily reduce operative time, contrast load, and device use, as well as hospital stay and procedure-related adverse events. Mean procedure time decreased from 5 hours for the first 12 cases to 3 hours for the last 16 cases, despite placing a higher number of mean snorkels per patient. Success initially with single-vessel Sn-EVAR procedures early in the series provided the experience necessary to address more challenging anatomic circumstances with multivessel snorkels over the course of the past 2 years. The two-surgeon approach also helped to minimize operative time, renal catheterization/occlusion time, and coordination of simultaneous deployment and balloon-molding interventions.

The precision provided by the fixed imaging suite also contributed significantly to the favorable outcomes. Because the Sn-EVAR technique often advances the proximal landing zone to the SMA orifice, precise visualization in full lateral position is necessary to accurately deploy the endograft, a position not well accommodated by portable imaging systems in general-purpose operating theaters. The tolerance required for successful proximal deployment and seal for Sn-EVAR is often measured in millimeters.

When reviewing complications encountered in this series, it is apparent (and somewhat expected) that procedures requiring single or double renal Sn-EVAR entail lower overall risks than the triple or quadruple snorkel strategies. Two of the four patients treated with three or more snorkels experienced significant reductions in postprocedure renal function, with one of them currently requiring permanent hemodialysis. Another triple-snorkel case required right arm access, the only one in our series, and although we had successful aneurysm exclusion, this patient sustained a postoperative stroke that led to her death, similar to the experience described by Coscas et al,[22] where a high proportion of those with right arm access for snorkel techniques had arch/cerebral complications.

On the basis of similar experience with increasingly complex anatomy, Bruen et al[21] have suggested that snorkel stent strategies be limited to two branch vessels for JAA repair and that the less functional/more challenging renal artery be sacrificed if the SMA needs to be stented. This strategy to minimize the number of snorkels makes intuitive sense because increasing the complexity and access needed to place multiple snorkel stents results in more operative time and potential problems. Rather than intentionally covering renal vessels, however, we believe further procedural modifications should be considered to improve outcome in multiple snorkel cases, including possibly combining snorkel, fenestration, and periscope access, or in some cases, staging procedures using sandwich or layered approaches to provide additional opportunities for branch vessel preservation.[24-26]

The types of snorkel stents used may influence technical success and, possibly, long-term outcomes. Self-expanding and balloon-expandable covered stents have both been deployed as snorkels, in this series as well as in prior reports. Given the complexity of the anatomy involved and variations in renal diameter, snorkel length, aortic atherosclerotic load, and tortuosity, a single approach will not likely be applicable to all patients requiring snorkel access. In our experience, the balloon-expandable snorkel stent is more efficient because the deployment and molding occurs in one step and precludes the additional wire and delivery catheter exchanges necessary when a self-expanding snorkel stent is used. For this reason, we have generally preferred the iCAST stent graft when sizing is appropriate and the stent graft is positionable, which is in agreement with prior reports.[20-22] The main reasons when we have had to use the self-expanding low-profile Viabahn stent graft include inability to advance the 7F sheath into the target branch vessels or significant tortuosity of the aorta above the snorkel neck. When using the Viabahn as a snorkel, the molding sequence requires withdrawal of the delivery catheter and readvancement of an additional balloon-expandable bare-metal stent placed within the Viabahn in regions that overlap the aortic endograft.

Issues related to covered vs noncovered stents deserve mention. Hiramoto et al[18] distinguished between the "encroachment" and "snorkel" procedures, and they successfully used noncovered stents to increase the proximal landing zone in selected cases. They further recommended that some amount of "suitable" neck exist below the region of the overlap of a bare snorkel stent and the main body endograft to use the snorkel strategy most effectively. We believe that the use of covered stents extends this concept

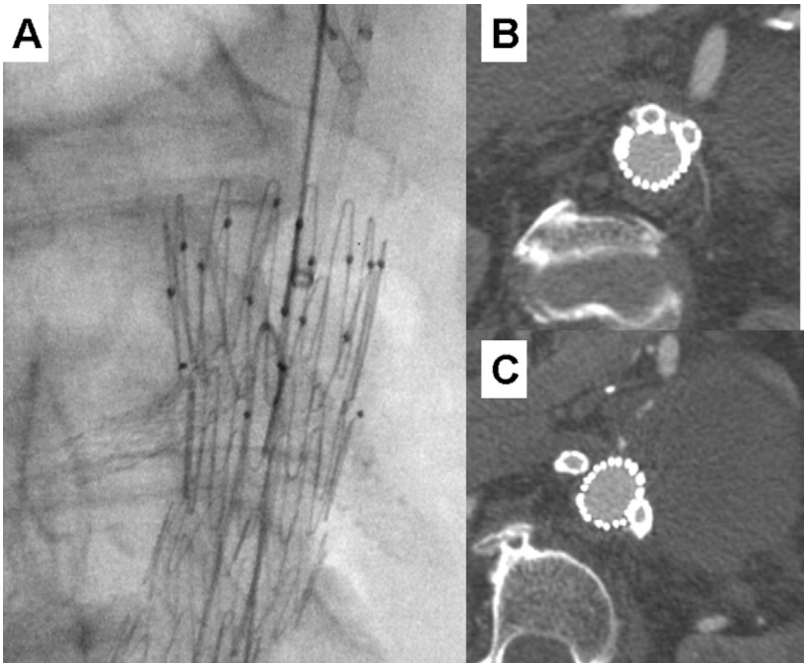

Fig 4. Crossing pattern **(A)** seen of most covered stents creating gutter **(B)** and indenting the main body of the endograft in follow-up **(C)**.

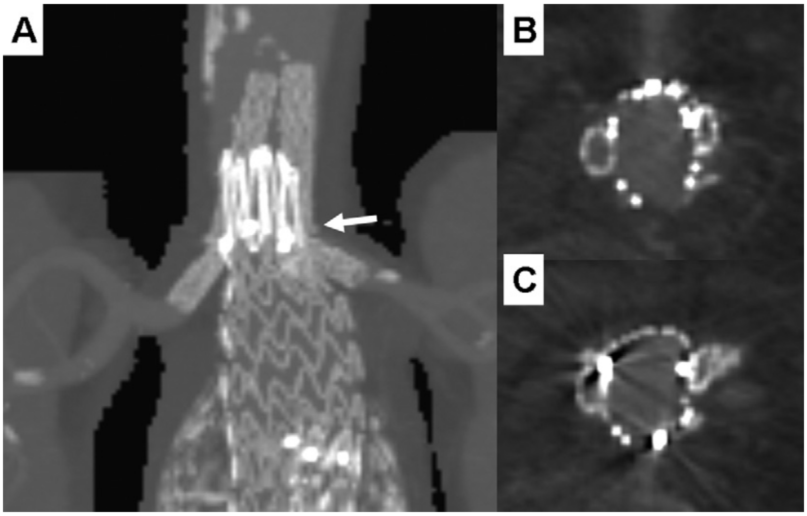

Fig 5. A, Kinked left renal snorkel iCAST stent (*arrow*), without flow abnormality **(B** and **C)**, seen on 6-month postoperative scan. This patient currently has neither endoleak nor renal compromise.

to even more challenging anatomy and provides successful management of JAAs by extending the seal zone past the renal arteries right up to the SMA in this series (Fig 4).

One potential long-term downfall to the Sn-EVAR strategy is the challenge in reobtaining access to the snorkel stent should there be a proximal endoleak or stent problem on postoperative follow-up. It is difficult to recommend, from this small series, how to approach type I endoleaks, and in fact, type I endoleaks in two patients in this series spontaneously resolved. Also, a kinked stent (Fig 5) with no change in renal function might be a harbinger of impending occlusion, but also unclear is the appropriate algorithm for this treatment. Our patient who occluded in follow-up was asymptomatic, without pain, creatinine rise, or noticeable blood pressure change, and the occlusion was incidentally noted on the 3-month CTA (Fig 6). The first postoperative CTA did not identify kinking or dislodgement of the snorkel stent.

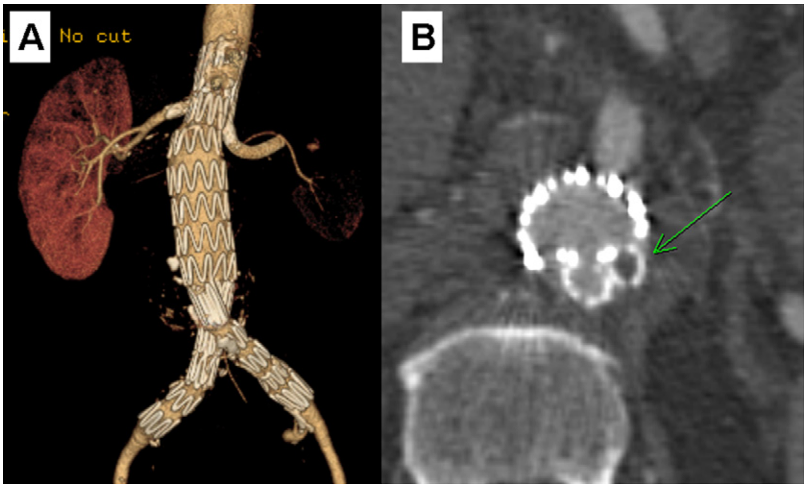

Fig 6. **A**, A three-dimensional reconstruction and a **(B)** postoperative scan at 3 months show an occluded left renal snorkel (*arrow*) found incidentally without renal compromise. Note the left renal parenchymal loss due to infarct in **(A)**.

This retrospective study has important limitations and the results should be interpreted cautiously. The most obvious issue is that this is not a randomized, nor even a controlled trial with any comparisons. Although Bruen et al[21] elegantly compared their institutional results with the chimney EVAR technique and concurrent open suprarenal AAAs and found improved outcomes in the endovascular group, this report represents a consecutive series without contemporary reference. However, in the United States, given the steady progression of endograft technology and patient preference for less invasive operative techniques, some derivative of the current snorkel/FBE/periscope techniques will likely prevail and extend EVAR options to essentially all patients with AAAs.

In the interim, however, our results and prior series noted in Table IV likely reflect a commitment to endovascular innovation inherent in high-volume aneurysm centers. The results therefore reported from these centers to date may not be widely applicable or generalizable to other centers or circumstances. Although Allaquaband et al[19] claim that chimney EVAR is "a simple technique that can be accomplished with off-the-shelf stents and stent grafts," we believe there is a significant learning curve to the steps and sequence of technical events to optimize outcomes with this approach. Our own results in this study and the review of the other series offer some optimism for Sn-EVAR; however, patients who are good physiologic risk or have contraindications at the planned snorkel neck should likely still be counseled about open repair pending longer-term data.

CONCLUSIONS

Until branched and fenestrated endografts become more widely available in the United States, the Sn-EVAR technique appears to provide suitable or even excellent short-term and intermediate-term results for elective AAA repair in high-risk patients as well as bailout or emergency circumstances. In our experience, the Sn-EVAR approach substantially improves the proximal neck anatomy and endograft landing zone, and with experience, single-renal or double-renal snorkel cases can be accomplished in ≤ 3 hours. By expanding on previously published techniques, we have been able to consistently achieve an adequate proximal seal in patients at high physiologic risk and unfavorable neck anatomy using commercially available devices without surgeon modification.

Early success with these techniques has made this our procedure of choice for complex short-neck to no-neck EVAR compared with surgeon-created fenestrated grafts or hybrid EVAR/open approaches. Although follow-up is still relatively short, our experience to date suggests that Sn-EVAR procedures have favorable outcomes and should be considered as viable alternatives to purpose-specific branched or fenestrated systems until the latter become more readily and generally available.

AUTHOR CONTRIBUTIONS

Conception and design: JL, JG, RD
Analysis and interpretation: JL, JG
Data collection: JL, JG
Writing the article: JL, RD
Critical revision of the article: JL, RD
Final approval of the article: JL
Statistical analysis: JL, JG
Obtained funding: Not applicable
Overall responsibility: JL

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Submitted Oct 4, 2011; accepted Nov 1, 2011.

DISCUSSION

Dr Linda M. Reilly (*San Francisco, Calif*). The authors report a retrospective series of 22 patients who underwent placement of snorkels to create a more proximal aortic seal zone and allow successful treatment of juxtarenal aortic aneurysms with conventional, commercially available endovascular stent grafts. Most of the patients had snorkels inserted into two or more visceral branches. The authors used covered stents exclusively and balloon expandable stents in most patients. The overall "bad" event rate (death, dialysis, branch occlusion) was three of 22, or 14%. There were two type I endoleaks that resolved spontaneously. The authors acknowledge that their follow-up remains relatively short and appropriately caution about the need for careful follow-up assessment. This series is slightly bigger than other published series (by one patient) and the results are comparable.

In general I don't have any major issues with any of the authors' conclusions or observations but I have a few questions:

1. First, what do you consider to be the new information you learned from treating this group of patients? We already know that one can insert one or more snorkel stents into the renal arteries to allow more proximal deployment of an aortic stent graft. We also already know that either bare stents or covered stents can be used. So what new information has your experience provided that can help us in the management of this particular anatomic challenge?
2. Based on your experience, are there anatomic factors that would eliminate a patient as a snorkel candidate? For example is there a minimum needed distance between the superior mesenteric artery and the most cranial renal artery? Is there a minimal renal artery diameter? What are the parameters of aortic neck size, including maximum and minimum diameter? Is there a limit to the degree of aortic neck angulation? What about the impact of renal arterial occlusive disease? In view of the outcome for the patients with more than two snorkels, do you believe patients who need more than two snorkels should never be offered the snorkel procedure?
3. With the potential risk of loss of renal perfusion, do you do anything different to assess renal function in these patients prior to the procedure to determine the patient's tolerance for renal mass loss if that were to happen? For example, do you measure creatinine clearance on all patients instead of just relying on serum creatinine?

4. Have you considered the potential impact of using covered stents on the risk of renal injury? When using a covered stent, one has to establish secure position of the covered stent in the renal artery to prevent inadvertent dislodging of the covered stent from the renal orifice, which is probably an irreversible event with inevitable loss of the kidney, as you experienced with one of your patients. The manuscript states that it is your goal to insert the covered stent 2 to 3 cm into the target artery. In order to insert the covered stent to that length, the wires, catheters, and sheaths must, of course, be inserted even further into the renal arterial tree to provide sufficient support. Positioning wires this deeply into the renal arterial tree increases the risk of branch perforation. This contrasts with the use of uncovered stents that do not need to be inserted a long distance into the renal artery, as their actual purpose is not to stent open the renal orifice but to maintain a flow channel outside the fabric of the aortic stent-graft.
5. You have a small study group and a low event rate, but have you looked at the "no-neck" versus "short-neck" groups to see if there are any differences that might have an implication for treatment success?
6. The manuscript states that you did not increase the oversizing of the aortic stent graft if more than one snorkel was planned. I wonder why not. Since success of the snorkel technique is dependent on the fabric of the aortic stent graft enfolding the snorkel to fill the gutters, it seems to me that more redundancy (oversizing) of the aortic stent graft might be a good thing if there is more than one snorkel. Could you comment, please?
7. I notice that you have some fairly large gutters between the aortic and renal components and I wonder if you used any Palmaz stents in the aortic neck to increase approximation and seal.

I suppose my real concern with the manuscript is that, to the lexicon of EVAR, TEVAR, FEVAR, and BrEVAR, the authors would now add Sn-EVAR and Ch-EVAR. I have to agree with Pat Clagett, MD—I think I think perhaps that is "too far."

I appreciate the opportunity to review the manuscript and look forward to your thoughts about these questions.

Dr Jason T. Lee. We would like to thank Dr Reilly for her insightful questions and the opportunity to provide additional clarification.

1. We believe our experience confirms the work of other groups as to the safety and efficacy of this technique in high-risk anatomy and high-risk patients with some caveats. Distinct from Bruen et al, we have not purposely sacrificed a renal artery when SMA revascularization is necessary and have utilized various periscope, terrace, and sandwich techniques to revascularize more than two side branches. We also learned that bare metal stents are not effective when placing the main body endograft well above the renal arteries and that covered stents are ideal for the snorkel strategy. Finally, the importance of a two-surgeon approach and fixed fluoroscopic imaging to aid in the conduct and imaging of the procedure cannot be underemphasized and has led to our improved results in the latter half of our experience.
2. Anatomic restrictions in our experience are similar to standard EVAR in that a "neck" of 10 mm is necessary, often without angulation and without thrombus. We still utilize standard EVAR devices, so 32-mm maximal diameter at the snorkel neck would be appropriate to treat. The smallest renal snorkels utilized were 5 mm, so a covered stent smaller than that is likely a poor choice for long-term patency. We concur that the >two snorkel cases had poorer outcomes and continue to look for adjunctive or better strategies towards revascularizing both renals and the SMA or celiac.
3. We will measure serum creatinine, calculate estimated GFR, and often obtain split-renal function tests to determine the viability of a kidney in the presence of renal artery stenosis.
4. Again, we believe covered stents allow the most caudal positioning of the main body endograft, providing maximal aortic wall apposition and decreasing type I endoleak changes. Positioning these snorkel stents well into the renal orifice allows more secure fixation. In the case where wire access was lost during deployment of the covered stent, we have learned that sequential partial deployment of the Viabahn using the sheath provides a more stable and accurate positioning of the snorkel stent.
5. All of our cases had necks <5 mm, and in our experience the outcomes of those with a snorkel neck of 0 mm versus a few mm were similar.
6. The oversizing of the main body endograft was typically 2-3 mm larger than what we would normally use for that neck diameter. This translated to 25-35% oversizing instead of 15-20% like usual without snorkel stents in place.
7. Palmaz stents were not used to provide any additional proximal radial force, and we would be concerned about crushing the snorkel stents with additional material in the main body endograft.